Marine Boundary-Layer and Air-Sea Interaction

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LONG-TERM GOALS

The long-terms goals of the research are to understand and parameterize the physics of air-sea interaction and the marine boundary layer over a wide spectrum of weather and ocean conditions.

OBJECTIVES

The main objectives of this effort are to study the air-sea interaction under different conditions which varied from trade winds off the east coast of Oahu, Hawaii during the Rough Evaporation Duct experiment (RED) to the stratocumulus marine layer off the central coast of California during the Cloud-Aerosol Research in the Marine Atmosphere I (CARMA-I) to the summertime mostly stable boundary-layer south of Martha's Vineyard, Massachusetts during the Coupled Boundary Layers/Air-Sea Transfer (CBLAST – Low winds).We are primarily interested in the determination of boundary-layer structure, the measurement of momentum, heat and water vapor (latent heat) air-sea fluxes and their spatial variability and parameterization of these fluxes.

APPROACH

The Navy CIRPAS Twin Otter research aircraft (which we instrumented with turbulence instrumentation for a previous ONR project, the Japan/East Sea experiment) was used to measure air-sea fluxes and boundary-layer structure during RED and CARMA-I in the summers of 2001 and 2002 respectively. Since the primary focus of CARMA-I was on the interactions between aerosols and clouds, many flux runs were also made in and at top of the stratocumulus cloud layer to quantify vertical transport in and near clouds.

For the summer 2003 CBLAST-Low experiment, we instrumented the CIRPAS Pelican aircraft (a modified Cessna 337 with only the pusher engine) with turbulence instrumentation similar to that of the Twin Otter. A picture of the Pelican aircraft with the main instrumentation is shown in Fig. 1. The flight patterns flown in CBLAST-Low mainly consisted of 30-m flux mapping legs, vertical structure profiles, and repeated legs across SST fronts and flux divergence legs over the WHOI Air-Sea Interaction Tower (ASIT).

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WORK COMPLETED

RED: Data from 12 research flights have been reprocessed and are being analyzed. Eddy correlation fluxes estimates were obtained from the 40-Hz data.
CARMA-I: The analysis of the 15 research flights is underway. So far the analysis of the turbulence data has focused on data from runs in and around cloud as cloud processing of aerosol is one of the main scientific goal of the experiment.

CBLAST-Low: We outfitted the CIRPAS Pelican aircraft with state-of-the-art turbulence and meteorological instrumentation including wind, temperature, humidity, infrared sea surface temperature and aircraft motion and navigation sensors. New flush static pressure ports were added on the fuselage as part of the research payload. Since the flow around the aircraft alters the static pressure field, determination of the difference between the measured static pressure from these ports and the true static pressure away from the aircraft in the same horizontal plane is required: this is called the static pressure defect or “position error” (Brown 1988). This correction was determined using the well-proven “trailing cone” technique during special test flights prior to CBLAST-Low deployment. As shown in Fig. 2, a semi-rigid tube with a static port is trailed far behind the aircraft in the undisturbed air allowing for a direct and instantaneous measurement of the pressure defect. It was found that for the Pelican’s 55 ms^{-1} nominal research true airspeed, the position error was almost zero. (Refer to Khelif et al., 1999 for further details on similar instrumentation and measurement techniques.)

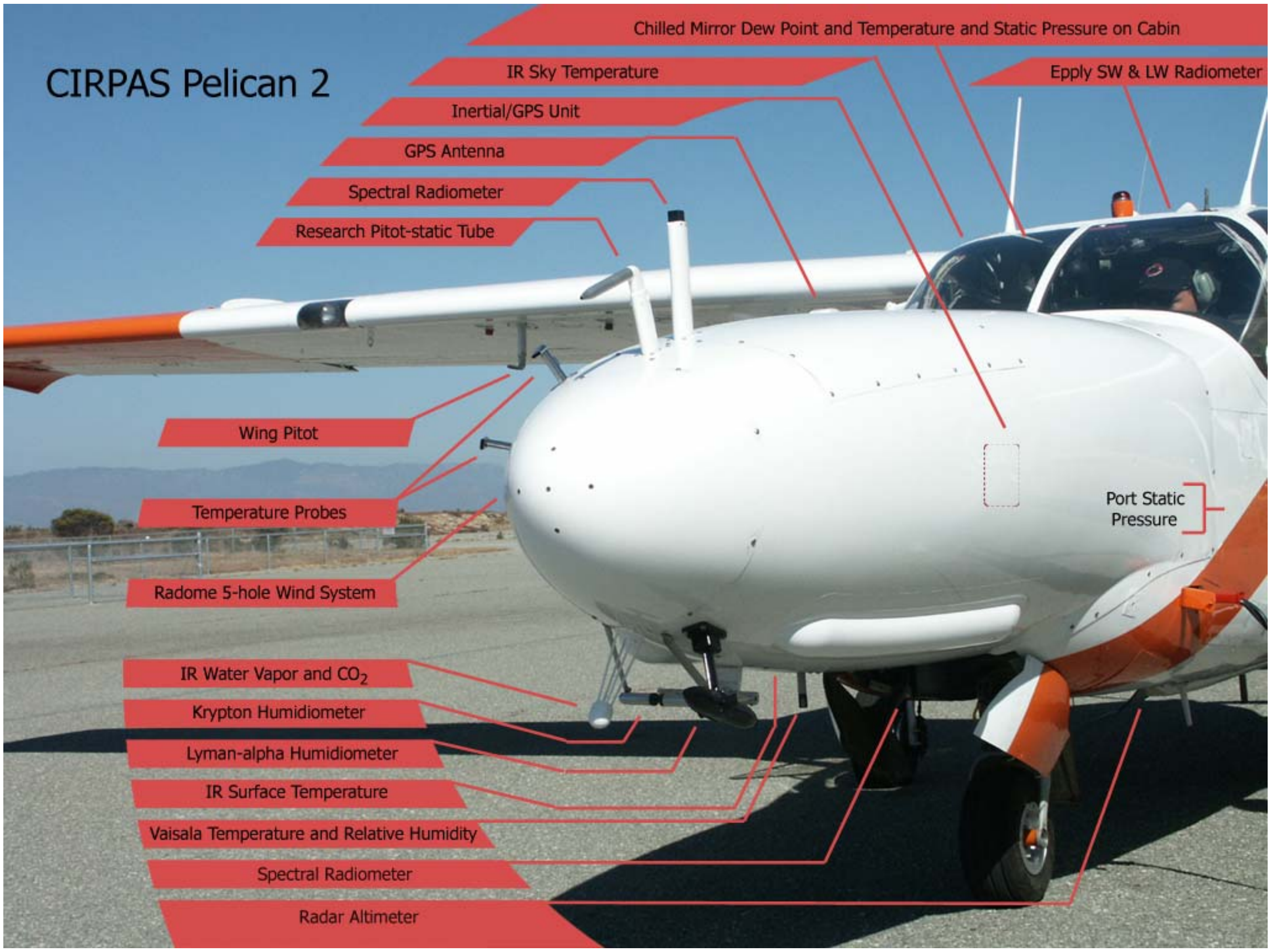

Figure 1 Main meteorological and turbulence instrumentation on the CIRPAS Pelican aircraft during the summer 2003 CBLAST-Low.

The Pelican flew 19 flights in CBLAST-Low and data were recorded simultaneously on two separate data systems aboard the aircraft for complete redundancy. Data from each flight were processed shortly after landing. Time series plots of the main variables, SST maps and data subsets were made available to the other CBLAST investigators on the same day as the flight at this URL: http://wave.eng.uci.edu/files/cblast/. Overall, very high quality turbulence data were obtained and no data were lost except for the flight of August 12 (030812) when the IR SST sensor failed. It was replaced with an identical spare for subsequent flights.

Figure 2 Calibration of the CIRPAS Pelican fuselage static pressure using the trailing cone technique.

RESULTS

a. RED

With the processed high-rate (40-Hz) data and from the definitions of the Reynolds averaged covariances between the vertical velocity fluctuations and fluctuations of the appropriate quantity, the along-wind stress, cross-wind stress, sensible heat and latent heat fluxes were calculated. The ogive technique (Friehe et al., 1991) was used. The fluxes were also estimated from the mean meteorological data using bulk aerodynamic formulas. The TOGA COARE algorithm (Fairall et al., 1996), which is suitable for the tropical conditions of RED, was used as well as a simpler formulation that does not account for the warm layer and cool skin effects. Figure 3 shows comparisons between the directly measured fluxes and the "bulk" fluxes of sensible and latent heats, and total stress from all runs below 50 m flown on 9 RED flights. While the agreement between eddy correlation and bulk estimates of latent heat flux and total stress seems reasonable, the bulk formulas consistently underestimated the sensible heat flux. Comparisons of the aircraft-measured SST (the one used in the bulk formulas) with that measured by the FLIP during aircraft flybys revealed the former was 0.5 to 0.75 ^{o}C less. This may be due in part to water vapor absorption and to the instrument windows not being cleaned before each flight. The underestimated SST values resulted in lower bulk fluxes of sensible heat. The temporal variability of the fluxes during RED is also nicely captured in Fig. 3.

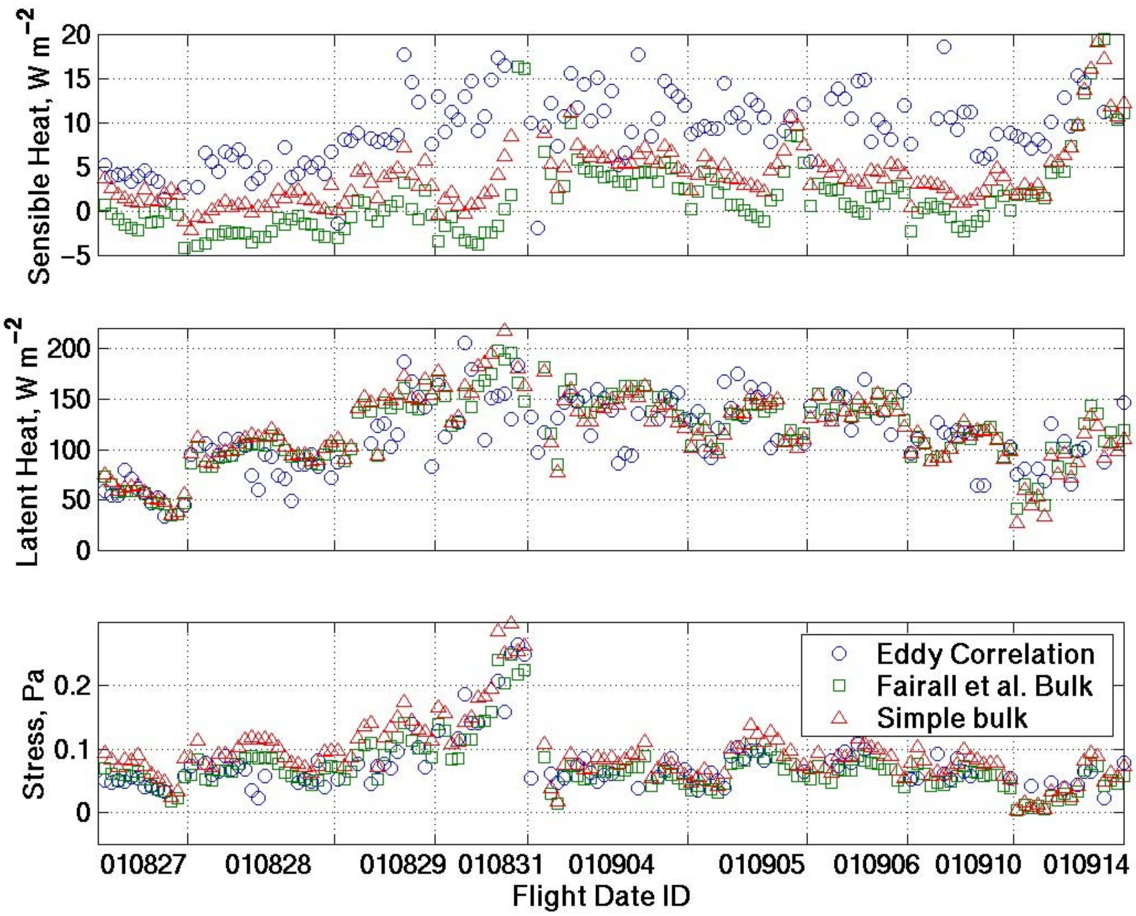

Figure 3. Eddy correlation and bulk estimates of sensible (top) and latent (middle) heat fluxes and total stress (bottom) obtained from all low level runs (z< 50 m) of 9 RED flights starting on August 27 and ending on September 14, 2001.

b. CARMA-I

The central coast of California boundary layer is characterized in the summertime by persistent marine stratocumulus deck few hundred meters thick with often well-defined strong inversions. An example of this is given in Fig. 4 showing profiles of ambient temperature and absolute humidity (water vapor density). Also shown in this figure are 40-Hz time series of fast-response absolute humidity, ambient temperature and vertical component of the wind obtained from a level run at cloud top (the height of the run is plotted as red dots on the profile plots). The anti correlation between the humidity and temperature data is very clearly shown. The detrainment of moister and colder air from the clouds below to the upper air is evidenced by the sudden increase in humidity and decrease in temperature at about 738 s, 742s and 755-756 s. Based on such data and associated aerosol data, our collaborator in this effort, Dean Hegg of the University of Washington, has shown that aerosol light-scattering efficiency of detraining air is significantly greater than that of non-detraining air. This suggests that cloud processing increases the aerosol light-scattering efficiency as hypothesized by Lelieveld and

Heintzenberg (1992). Dean Hegg is the lead author on a recently submitted paper detailing this important CARMA-I finding.

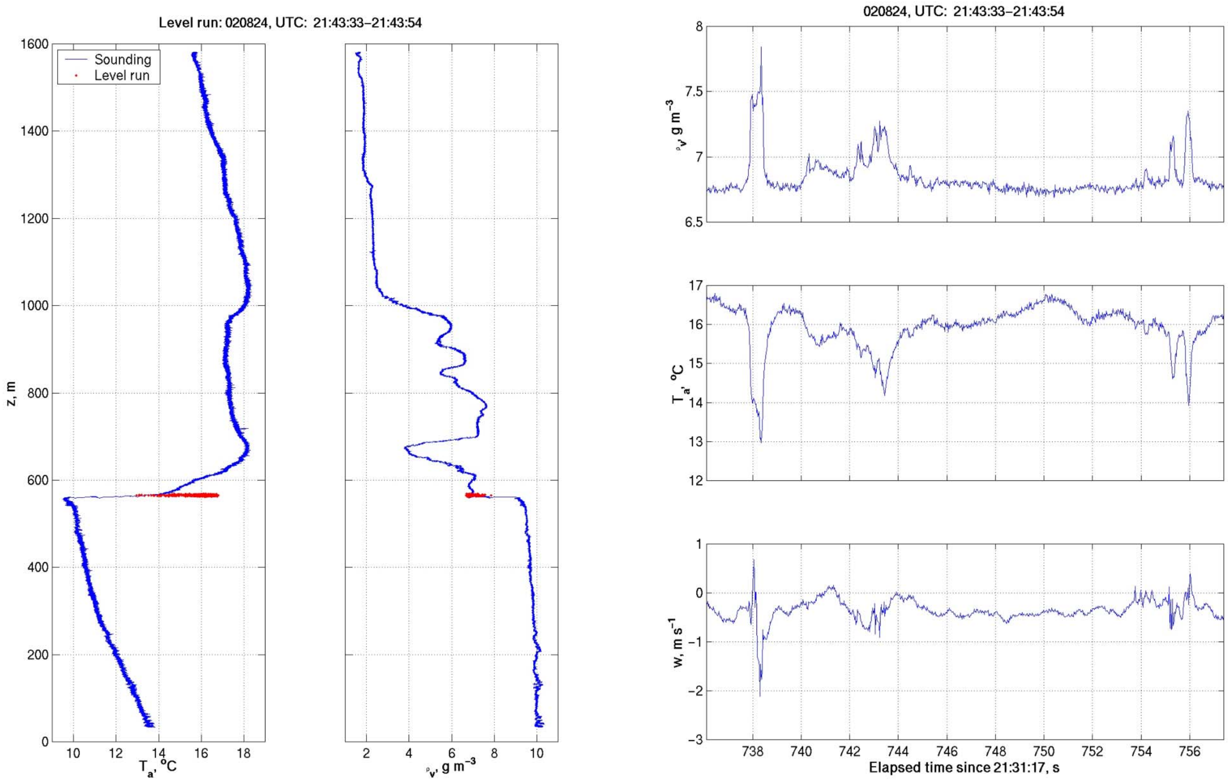

Figure 4 CARMA-I data showing on the left panel profiles of ambient temperature, T_a, and water vapor density, and, on the right panel time series of water vapor density (top), ambient temperature (middle) and vertical component of the wind (bottom) obtained from a level run corresponding to the elevation indicated by the red dots on the left panel plot.

c. CBLAST-Low

The SST variability south of Martha's Vineyard obtained from a typical CBLAST-Low flux mapping flight on August 8, 2003 is shown in Fig. 5. It was a clear day with northeasterly moderate winds (roughly 7 ms^{-1}). The map reveals a cool water band at about 17.5 ^{o}C extending across the central part of the mapped area. The largest SST gradient (> 6 ^{o}C) was observed at the southern edge of this cool band where it meets a warm tongue with temperature of roughly 22.5 ^{o}C.

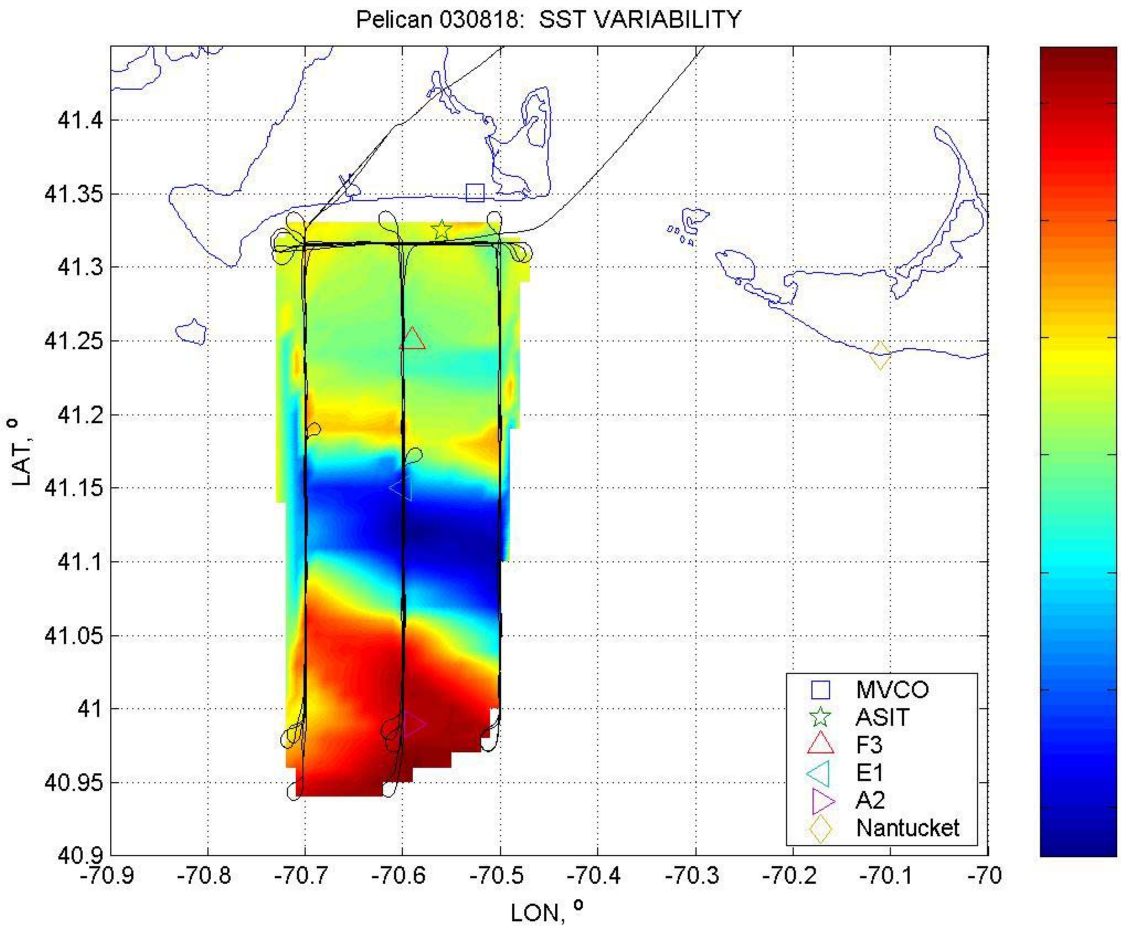

Figure 5 Variability of SST in the CBLAST-Low research area on August 18, 2003. Data are from the CIRPAS Pelican Heiman KT19.85 IR thermometer. The Pelican flight pattern is overlaid in black.

Part of the flight track shown in Fig. 5 above was dedicated to fly back-and-forth across the sharpest SST gradient to investigate the response of the overlaying air to the sudden changes in SST forcing. Time series of aircraft heading, SST, SST-ambient temperature difference, and fluctuations of the vertical component of the wind, *w'* obtained from the 40-m runs across the SST front on the middle NS track are given in Fig. 6. It clearly shows that when the difference SST-ambient temperature switches from negative to positive (stable to instable), the intensity of turbulence switches from suppressed to very intense as evidenced by changes in *w'* from about ± 0.2 ms^{-1} to about ± 1 ms^{-1}. More detailed analysis is planned for CBLAST-Low data.

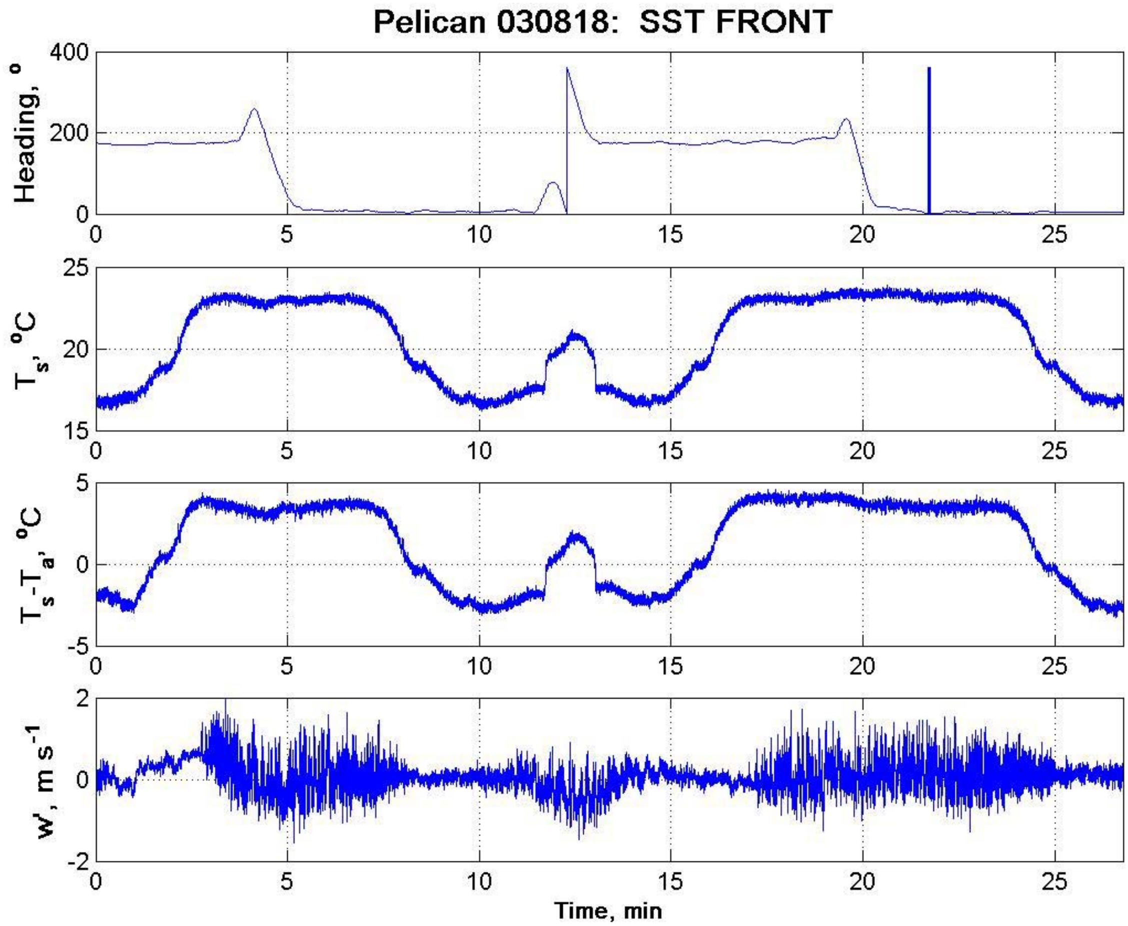

Figure 6 CBALST-Low data from August 18, 2003 showing time series across SST front of, from top to bottom, aircraft heading, SST, SST-ambient temperature difference and fluctuations of the vertical component of the wind. Data are from middle track on the SST map of Fig. 5 above.

IMPACT/APPLICATIONS

The combination of aircraft cutting edge aerosol and turbulence instruments as in CARMA-I is already yielding new insight in the role of cloud processing on aerosol light-scattering efficiency. The high-quality turbulence and meteorological aircraft data obtained during CBLAST-Low provided good spatial (both horizontal and vertical) coverage of the CBLAST research area and captured many unique events such as the switch from stable to instable conditions across SST fronts. Their analysis will help us improve our understanding of the air-sea interaction mechanisms. The data will also be very useful for mesoscale models such as COAMPS (collaboration with Prof. Qing Wang of NPS) and LES models (collaboration with Peter Sullivan, NCAR).

TRANSITIONS

The CIRPAS Pelican aircraft has a new capability with the turbulence instrumentation package we installed for CBLAST-Low. The operation of this single engine, single pilot aircraft is significantly more cost effective compared to a lager aircraft and still it can fly for over 5 hours on a research flight.

RELATED PROJECT

The summer 2001 data from the CIRPAS Twin Otter are part of Rough Evaporation Duct (RED) experiment (http://sunspot.spawar.navy.mil/red/). The summer 2003 Pelican data are part of CBLAST-Low (http://www.whoi.edu/science/AOPE/dept/CBLAST/lowwind.html).

REFERENCES

Brown, E.N., 1988: Position error calibration of a pressure survey aircraft using a trailing cone. NCAR/TN-313+STR, 29 pp. [Available from NCAR, P.O. Box 3000, Boulder, CO 80307.]

Fairall, C.W., E.F. Bradley, D.P. Rogers, J.B. Edson, G.S. Young, 1996: Bulk parameterization of air-sea fluxes for Tropical Ocean Global Atmosphere Coupled-Ocean Atmosphere Response Experiment J. Geophys. Res., 101, C2, 3747-3764.

Friehe, C. A., Shaw, W. J., Rogers, D. P., Davidson, K. L., Large, W. G., Stage, S. A., Crescenti, G. H., Khalsa, S. J. S., Greenhut, G. K., and Li, F., 1991: Air-sea fluxes and surface-layer turbulence around a sea surface temperature front, J. Geophys. Res., 96, C5, 8593-8609.

Lelieveld, J. and J. Heintzenberg, 1992: Sulfate cooling effect on climate through in-cloud oxidation of anthropogenic SO2, Science, 258, 117-120.

Khelif, D., S.P. Burns and C.A. Friehe, 1999: Improved wind measurements on research aircraft, J. Atmos. Oceanic Tech., 16, 860-875.

PUBLICATIONS

Journal Articles:

Burns, S.P., D. Khelif, C.A. Friehe, A.G. Williams, P. Hignett, A.L.M. Grant, J.M. Hacker, D.P. Rogers, E.F. Bradley, R.A. Weller, M.F. Cronin, S.P. Anderson, C.W. Fairall, and C.A. Paulson, 1999: Comparisons of aircraft, ship, and buoy meteorological measurements from TOGA COARE. J. Geophys. Res., 104, 30,853-30,883.

Burns, S.P., D. Khelif, C.A. Friehe, P. Hignett, A.G. Williams, A.L.M. Grant, J.M. Hacker, D.E. Hagan, Y.L. Serra, D.P. Rogers, E.F. Bradley, R.A. Weller, C.W. Fairall, S.P. Anderson, and C.A. Paulson, 2000: Comparisons of aircraft, ship, and buoy radiation and SST measurements from TOGA COARE. J. Geophys. Res., 105, 15,627-15,652.

Hegg, D.A., D.S. Covert, H. Jonsson, D. Khelif and C.A. Friehe, 2003: Observations of the impact of cloud processing on aerosol light-scattering efficiency. J. Geophys. Res. [Submitted, refereed]

Khelif, D., C.A. Friehe, H. Jonsson, Q. Wang and K. Rados, 2003: Surface forcing and boundary-layer structure over the Japan/East Sea during cold-air outbreaks. Deep Sea Res. [Submitted, refereed]

ABSTRACTS

Khelif, D. and C. A. Friehe, 2000: Surface Forcing and Boundary-Layer Structure Over the Japan/East Sea During Winter Cold-Air Outbreaks. Fall Meeting of American Geophysical Union, San Francisco, 15-19 December.

Khelif, D. and C. A. Friehe: 2001: Air-Sea Fluxes and Boundary-Layer Structure Over the Japan/East Sea During Winter Cold-Air Outbreaks. The Oceanography Society Biennial Scientific Meeting, Miami Beach, 2-6 April.

Khelif D. and C.A. Friehe, 2003: Marine atmospheric boundary-layer structure and air-sea fluxes under moderate trade winds regime. Preprints, 12th Conference on Interactions of the Sea and Atmosphere Long Beach, American Meteor.

Wang, Q., H. Zuo, J. Kalogiros, C. Friehe, D. Khelif and H. Jonsson, 2000: Evaluation of surface flux and Boundary Layer Parameterizations in COAMPS using JES aircraft measurements. Fall Meeting 2000, American Geophysical Union, San Francisco, 15-19 December.

Whisenhant, M.K., Q. Wang, S. Wang, J.D. Doyle, D. Khelif and C.A. Friehe, 2001: Grid Resolution and Surface Flux and Boundary Layer Parameterizations in High-resolution Mesoscale Models. Ninth Conference on Mesoscale Processes, Fort Lauderdale, FL, July 30 - August 2, 2001